

# Why Atens Enjoy Enhanced Accessibility For Human Space Flight

Daniel R. Adamo\*  
Houston, Texas 77059

and

Brent Wm. Barbee†  
NASA Goddard Space Flight Center, Greenbelt, Maryland 20771

## Extended Abstract

IN the context of human space flight (HSF), the concept of near-Earth object (NEO) accessibility is highly subjective [1]. Whether or not a particular NEO is accessible critically depends on mass, performance, and reliability of interplanetary HSF systems yet to be designed. Such systems would certainly include propulsion and crew life support with adequate shielding from both solar flares and galactic cosmic radiation. Equally critical architecture options are relevant to NEO accessibility. These options are also far from being determined and include the number of launches supporting an HSF mission, together with whether or not consumables are to be pre-emplaced at the destination.

Until the unknowns of HSF to NEOs come into clearer focus, the notion of *relative* accessibility is of great utility. Imagine a group of NEOs, each with nearly equal HSF merit determined from their individual characteristics relating to crew safety, scientific return, resource utilization, and planetary defense. The *more* accessible members of this group are more likely to be explored first.

A highly accessible NEO could conceivably be deferred in favor of a less accessible HSF destination because the latter is more accessible during a programmatically desirable launch season. Such a season is really yet another undetermined HSF architecture option. A launch season's duration will likely be measured in weeks, and it will be utilized at an indeterminate point almost certainly more than a decade in the future when HSF programmatic maturity is sufficient.

Furthermore, current knowledge of the NEO population relevant to HSF is far from complete. In the 100-m-diameter class of greatest interest, only a few percent of the estimated NEO population is known [2, Figure 2.4]. Therefore, any known, lost, or fictitious NEO in a highly accessible orbit is a potential HSF destination of merit. Even if lost, fictitious, small, or hazardous, such a *potential* target (or another in a similar orbit) may ultimately prove to be an early HSF destination when the pertinent NEO population is more thoroughly catalogued and NEO orbits are more thoroughly maintained at high accuracy.

This paper first reviews methodology and pertinent results from NASA-sponsored research performed in late 2010 and dubbed NEO HSF Accessible Targets Study (NHATS, pronounced as "gnats"). A useful accessibility metric developed during this study is  $n$ , the tally of NHATS-

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\* Astrodynamics Consultant, 4203 Moonlight Shadow Court; [adamod@earthlink.net](mailto:adamod@earthlink.net). Senior Member AIAA.

† Flight Dynamics Engineer, Code 595, 8800 Greenbelt Road. Member AIAA.

compliant mission trajectory solutions detected in association with a specific NEO. The known NEO population is then surveyed to illustrate in which regions of heliocentric semi-major axis, eccentricity, and inclination ( $a, e, i$ ) space NEOs with large  $n$  values are mapped. The ( $a, e, i$ ) mapping is also formatted such that membership in each of four NEO orbit classifications, as defined below, is evident.

*Amors* have orbits everywhere superior to (outside of) Earth's. An Amor is therefore defined to have perihelion between 1.017 astronomical units (AU) and the maximum NEO value of 1.3 AU. As of 0 hrs Universal Time on 1 January 2011 (UT epoch 2011.0), Amors numbered 2855 in the Jet Propulsion Laboratory (JPL) Small-Body Database (SBDB)<sup>‡</sup>, comprising 37.7% of known NEOs.

*Apollos* have orbits crossing Earth's with periods greater than Earth's. An Apollo is therefore defined to have perihelion less than 1.017 AU and  $a$  greater than 1.0 AU. As of 2011.0 UT, Apollos numbered 4080 in the SBDB, comprising 53.9% of known NEOs.

*Atens* have orbits crossing Earth's with periods less than Earth's. An Aten is therefore defined to have aphelion greater than 0.983 AU and  $a$  less than 1.0 AU. As of 2011.0 UT, Atens numbered 618 in the SBDB, comprising 8.2% of known NEOs.

*Atiras* have orbits everywhere inferior to (inside of) Earth's. An Atira is therefore defined to have aphelion less than 0.983 AU. As of 2011.0 UT, Atiras numbered 11 in the SBDB, comprising 0.1% of known NEOs.

It is no surprise that the largest  $n$  values are chiefly associated with Apollos and Atens. Because these orbits cross Earth's, distance to be covered in a given round trip mission time  $\Delta t$  can be far less than is possible for Amors or Atiras [1, Figure 7]. This  $\Delta t$  or the sum of mission propulsive impulse magnitudes  $\Delta v$  can more frequently be minimized to enhance NHATS compliance for Apollos and Atens than is generally the case for Amors and Atiras.

A less intuitive trend in NHATS results is that Atens nearly outnumber the more numerous Apollos among the most compliant NEOs as measured by  $n$ . This trend is completely out of proportion to the degree Atens are represented among the known NEO population. A theory based on geocentric NEO dynamics is presented by this paper to explain why Atens enjoy inherently greater accessibility than do Apollos.

Another trend evident from mapping into ( $a, e, i$ ) space is the dearth of known NEOs at low  $e$  when  $a < 1$  AU. Underrepresentation of Atens and Atiras in the NEO catalog is at least in part attributable to observing exclusively from a perspective near Earth [2, pp. 41-49]. Generally inferior Aten and Atira orbits are rarely, if ever, in Earth's night sky [2, Figure 3.5]. Until a comprehensive NEO survey is conducted from an appropriate region remote from Earth, the theory developed in this paper indicates a substantial fraction of the most accessible NEOs will remain unknown.

## References

- [1] Adamo, D. R., Giorgini, J. D., Abell, P. A., and Landis, R. R., "Asteroid Destinations Accessible For Human Exploration: A Preliminary Survey in Mid-2009", *Journal of Spacecraft and Rockets*, Vol. 47, No. 6, AIAA, Washington, D.C., 2010, pp. 994-1002.

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<sup>‡</sup> The SBDB may be accessed via a search engine at [http://ssd.jpl.nasa.gov/sbdb\\_query.cgi](http://ssd.jpl.nasa.gov/sbdb_query.cgi) or via a browser at <http://ssd.jpl.nasa.gov/sbdb.cgi> [verified 1 January 2011].

- [2] National Research Council Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies, *Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies: Final Report*, The National Academies Press, Washington, D.C., 2010.